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AN OPEN SEA MODULAR CONSTRUCTION METHOD: RIGID PONTOON CONNECTORS

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ABSTRACT

This paper discusses a current effort by the U. S. Navy to establish the technology required for open-sea assembly of pontoon-based floating platforms in moderate seaways. The emerging technology substantially enhances the mobility and utility of platforms and hence increases the practical value of such floating assets. The favored connection system operates in a progressive manner, incorporating an innovative hardware arrangement which with proven rigging methods is highly adapted to the severe relative motion between adjoining pontoons weltering in hostile seas. The same connecting system functions in calm-water conditions also. This presentation includes the rationale of design, technical problems, and overview of the conceptual connecting system, as well as supporting experimental results.

Keywords: Pontoons, modular constructions, rigid connectors, open seas, progressive connection methods

INTRODUCTION

Floating pontoon assets are used extensively by the Navy. At present, most pontoon structures used in seaway applications are pre-assembled on land. The relatively large size of these structures often presents a formidable sealift burden. This drawback substantially limits the application versatility of this simple prodigy. Consequently, commercial pontoons have made the transition to ISO compatibility for shipping and storage advantage. In this vision, pontoon modules are deployed to marine areas by standard container ship for assembly at sea, as depicted in Figure 1. Regardless of the construction of pontoon modules, a critical premise for the success of modularization is the capability of rapidly assembling a large number of pontoons in a seaway. Modular construction of pontoon-based structures includes two types of connections -- rigid or flexible. A rigid construction provides a continuous deck surface for flexible deck layout, while a flexible joint substantially reduces the bending stresses so the modules can be designed with better structural efficiencies. Tradeoff is necessary to make the facility design practical and economical. This paper addresses rigid connection technology. Flexible connection technology is deferred to a follow-on paper.

STATUS OF THE TECHNOLOGY

Technology suitable for constructing rigid barges in open seaways from pontoon modules does not exist at present. A prior survey (Huang, 1995) indicated that commercial connection systems are mostly flexible joints for inland water use. Most designs utilize delicate jacking systems and sophisticated rigging systems, which appear rather fragile for open sea operations. Some systems further require special hull geometry to actuate barge alignment for connection. A very common practice is to fit the bow of a tug in a stern notch or cradle. Others use a rigid push frame hinged to the tug. Both use tension members to hold the barge together. These systems are heavy making connections in open seas difficult. The Navy's NL (Navy Lightered) barges are constructed on land as described in the Navy's pontoon gear manual (NAVFAC, 1994). The Army's MCS barges are partially assembled on deck of a specialized ship before launching for final assembly in the water with a method inherited from the use of commercial pontoons

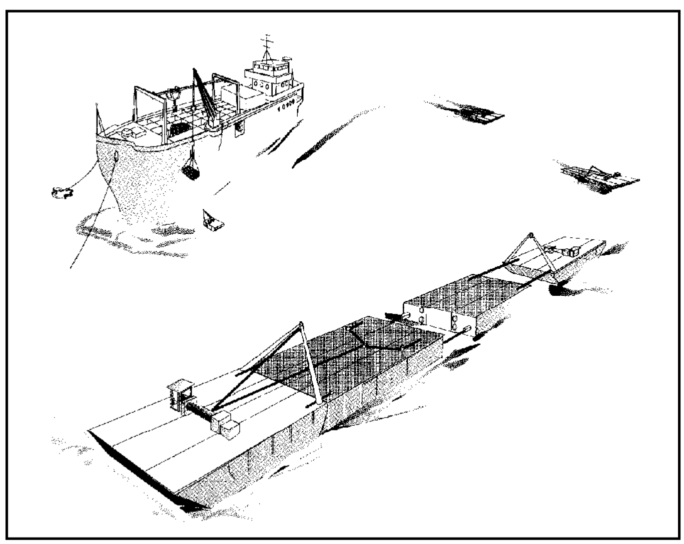

Fig. 1 Scenario of open sea modular construction method.

(Department of Army, 1990). This method uses a large number of small stab pins which are secured by guillotines. This procedure is both time and labor intensive, and requires precise alignment between connection components. Such connections can be made only in an essentially calm water condition.

SYSTEM REQUIREMENTS

Pontoons suitable for transport by container ship are sensitive to the prevailing sea states near shore. Analysis (Paulling and Huang, 1995) indicates that large relative motion and dynamic load occur at the connecting ends of the pontoons. For example, in a typical sea state 3 condition, the connecting ends of two 40-foot (12.19-m) pontoons situated in line at a separation of 10 feet (3.04 m) with long axes heading into the waves, as shown in Figure 2, oscillate at a 5-foot (1.52 m) elevation differential, with relative heave and surge attaining maximum speeds of 5 fps (1.52 m/s). For a connecting system to be feasible on open water, it must somehow accommodate the random motion of pontoons. In particular, the system must perform four basic functions without causing damage to the pontoons or itself. To meet the needed functional requirements, it must (a) bring the pontoons together; (b) restrain the relative movement; (c) provide collision protection; and, (d) withstand the associated dynamic load. It is clear that with appreciable relative motion, a safe connecting system should not require direct personnel involvement in the vicinity of the adjoining pontoon ends. All of these requirements must be realized with components configured within the geometry of a flush, box-shaped module compatible with accepted ISO (International Organization for Standarizations) standards. Any projection from end or side faces will either impair the suitability for transport by containerships or reduce the effective capacity of the module.

In addition to the functional requirements, there are operational requirements within the military arena as well. In order to meet the projected needs of future amphibious operations, a connector must allow assembly of barges from individual pontoon modules on open water up to sea state 3, with survival of assembled structures through sea state 5. Assembly must be quick, on the order of 30 minutes to join two individual modules. The operation and maintenance of connectors must not require any unusual skills or training aside from the level of competence typically provided by Navy instruction for equivalent functions. In the system being developed, many of the mechanical functions are conceived as automated or semi-automated to minimize the need for human interface, and also to minimize the dangers of those dexterous activities required. In addition, connectors must be repairable, or at least removable, on site to avoid the costly need for specialized maintenance facilities and to prevent undesired interruptions in service. The model presented here houses connector components in serviceable modules that can be raised in place for maintenance and repair, or removed whenever replacement is required. They must be constructed sufficiently light in weight, however, so that no specialized lifting gear are required above those assets normally available to the amphibious construction crews. The connectors must also be generic enough in function so that dedicated tender boats are not required for support, but rather modules can be connected when necessary using alternate vessels of convenience.

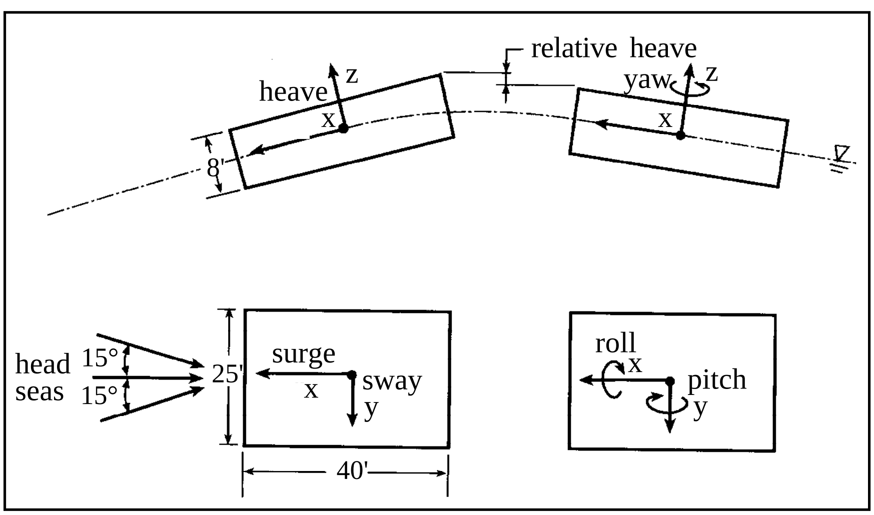

Fig 2. Definition of terminology.

BASIC CONCEPT

Using the guidelines above, a suitable connecting method is envisioned to progress as follows: (a) connect the modules at a safe distance with cables; (b) draw the modules together under pretension; (c) restrain the relative motion and align the modules for connection; and (d) lock-in load bearing connectors. This procedure eliminates the relative motion between modules step by step in a sequential manner. The procedure demonstrates a favorable potential for accommodating the random nature of seaways and, even using it to actuate the connection. The method does not require action by personnel or transfer of personnel and equipment across the adjoining ends during the connecting process. The procedure does not require precise module maneuvering exceeding the standard practice of tug operation. A conceptual rigid connection system that appears to have good potential for meeting the basic requirements specified above is illustrated in a small scale table top model shown in Figure 3. This conceptual model consists of a rigging system that gradually draws the pontoons together under pretension and near the end leads a pair of compliant alignment pins into mating receptacles. These alignment pins reduce the relative heave and sway to allow a smooth engagement of four spring supported stab pins -- pins that once inserted are further locked within the receptacles by guillotines. Spring supports behind the stab pins retract on impact, allowing the pins to also serve as fenders between the pontoons. The connection is performed in a progressive manner under positive control of tender boats during the entire process. The tender boats use opposing thrust to pull mating modules away from one another, providing a reasonable pretension on the bridle legs that reduces the possibility of snap loads. Power and winches are provided by these tugs. Little human interaction is required other than to coordinate the tender boats to engage the connectors. This arrangement is especially attractive under the dangers of open sea operations.

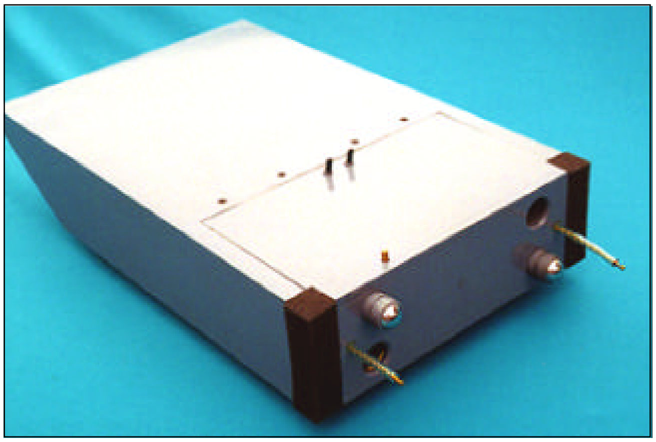

Fig. 3 Scale model of the recommended rigid connection system.

CONFIGURATION

The overall arrangement of components in the new connecting system is pictured in Figure 4. The system is modular in construction so that all components except the intermediate-connecting alignment pins are housed within the universal, removable structural frame as shown. The entire module may be raised to deck level for maintenance, repairs, or replacement. Modules on the port and starboard sides are identical copies, but with inverted orientation. Thus only one type of module has to be maintained for replacement. The alignment pins are stowed in cylindrical housings attached to the pontoon at mid-height just outboard of the rigid connector modules. An elastomer corner fender is installed at each vertical edge of the pontoon. Details of individual components are provided in the paragraphs that follow.

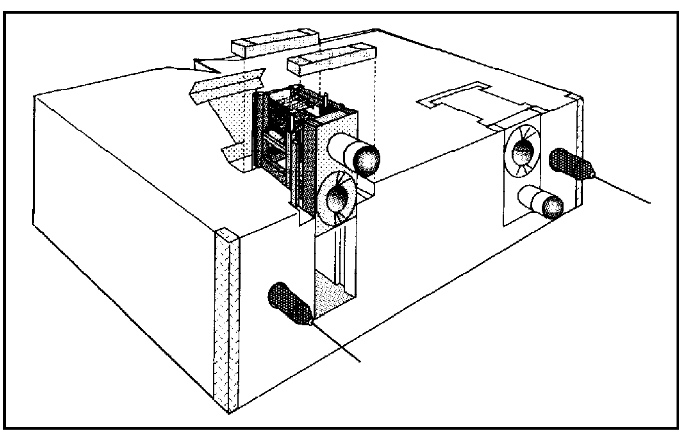

Fig. 4 General layout of the rigid connection system.

Rigid Connector Module: Stabbing Pins and Receptacles

Detailed structural layout of the rigid connector assembly is illustrated in Figure 5. Each connector module contains a spring-loaded stab pin and a pin receptacle. Stab pins perform a dual function as temporary fender as sections come together and as permanent load bearing member after a connection is completed. In a connection sequence, two large diameter stab pins are located on the interface at the opposite corners and two receptacles are at the other corners. Identical counterparts are equipped on the other pontoon. These pins are retractable for shipping and should be extended before modules are within a distance of possible collision. The stab pin rests on a spring support contained in a circular cartridge to form a resilient member sliding back and forth together. This member at the fully extended position will be held at the inboard end of the cartridge preventing it from back sliding. In case that the pins do not find the receptacles at once due to the random movement between modules, they are likely to press against the vertical plate of the other module. The spring-loaded pins will retract as shown in Figure 6 to absorb the impact energy as a fender system to protect the modules as well as the pins before they are properly located in the receptacles. Therefore, this connection system does not require simultaneous alignment of all connector members. It works gradually and takes advantage of random wave-induced motion to find the receptacle by means of hit-or-miss action. Shallow funnels are equipped around the receptacles for the stab pins (Figure 4) to assist in the location of the pins. The funnel-shaped surface around the receptacle tends to guide the stab pins into the receptacle under wave-induced motion. The pins when locked to the receptacles carry the tensile loads induced by weights and motions. The connector frames, on the other hand, carry the compression loads.

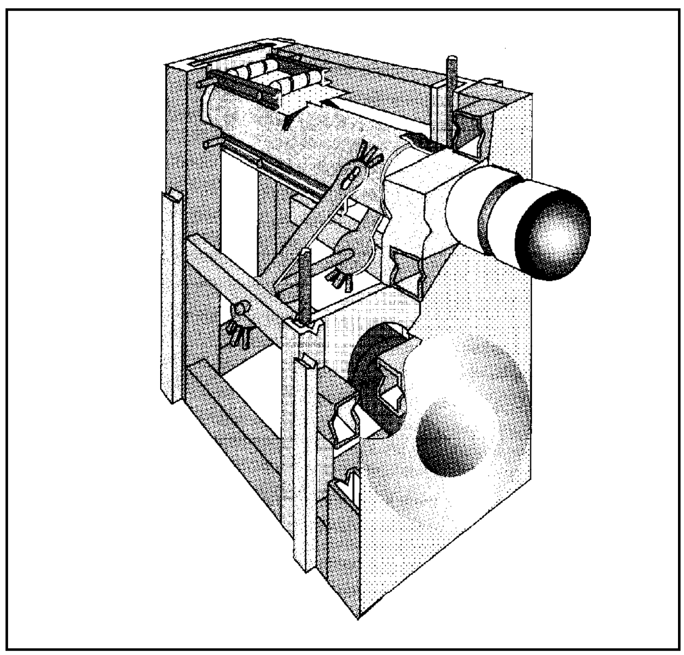

Fig. 5 Structure layout of the rigid connector.

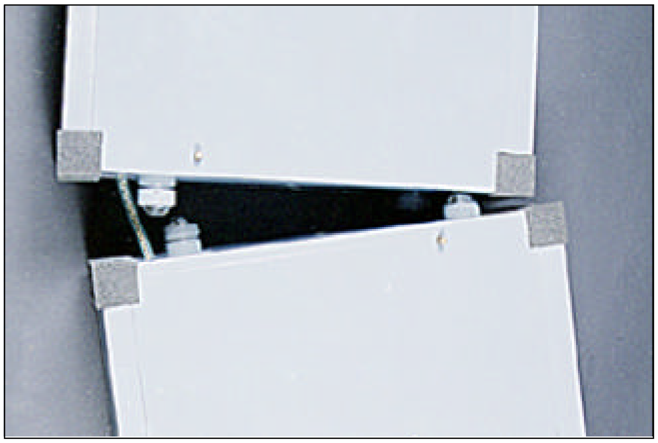

Fig. 6 Spring loaded stab pins work as fenders.

Alignment Pins

Alignment pins provide the transition between free floating individual pontoons and hinged couple as mating takes place. Alignment pins are stowed in a housing fixed to the pontoon structure itself, outboard of the connector modules. A section of chain molded in an elastomer (or covered in an elastomer sleeve) is attached to the towing line at the outboard end and is loosely connected to the bottom of the stowage housing at the inboard end as shown in Figure 7. The chain section is extended from the stowage housing by the towing line during mating, and is subsequently guided into the matching receptacle for temporary alignment of the modules. The stowage housings and receptacles are identical such that the alignment pins may be stored in either pontoon module. The chain section substantially reduces relative motion between modules while also being sufficiently flexible to accommodate bending.

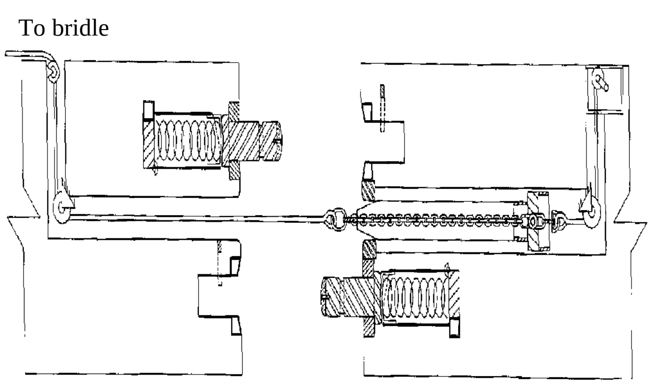

Fig. 7   Alignment pin conception.

Rigging System

The pontoons are brought together with a special rigging arrangement refererd as the bridle marriage connection system, shown symbolically in Figure 1. One end of a cable is attached to warping lines that run from the winch on the leading tug over the deck of the module it controls. The other end splits into two "Y" shaped branches, each of which is shackled to an alignment pin on the other pontoon. While the tugs run at constant throttle in opposite directions, the winch attached to the marriage bridle slowly pulls the modules together. The two tugs pulling in the opposite direction keep the warping lines in tension to reduce the chance of allowing snap loads on the warping lines. In close proximity, these warping lines tend to align the causeways and lead the alignment pins into the receptacle. Although the alignment pins are not designed to resist the shear loads, field and model basin observations indicate that these pins effectively reduce the relative translations to allow a smooth engagement of the rigid connector pins.

Corner Fenders

A pair of elastomer fenders are located at the vertical edges on each end of the pontoon to protect against the sharp corners.

CONNECTING PROCEDURE

The connecting process begins the moment that modules are launched from the delivery ship. A tug meets the module at the ship side taking over control of the modules and tows it to an open site for further connection as illustrated by Figure 1. A pair of these tug and module combinations are brought together at roughly a 40-foot (12.19 m) separation. Messenger lines are passed between the modules to lead the marriage bridle legs for initial connection. The tugs then pull the modules away from each other to establish and keep a reasonable pretension on the bridle legs to avoid possible snap loads. Meanwhile, the winch gradually rewinds the marriage bridle legs and leads the alignment pins into the receivers. At a short separation distance, the chain sections will roughly align the adjoining ends and substantially reduce the relative heave between the modules. The spring-loaded stab pins are extended before this moment. Further retraction in the bridle legs closes up the gap and the stab pins are likely to land on the side wall of the adjoining modules if they do not find their respective matching receivers. In this case, the spring-loaded pins work as bumpers to protect the modules. At this moment, the pins undergo random motion and eventually find the shallow funnel access around the receivers and slide into the receivers. This process, which does not require precise alignment of all connecting members simultaneously, has a much better chance to work in the open seaways. In the procedure, the two positioning tugs are connected end-to-end with matching pontoon module to form an in-line configuration as depicted in Figure 1. This method has proven less risky in elevated sea states than an alternate scheme of attaching tugs to the sides of joining modules.

EXPERIMENTAL VALIDATION

Test Setup

The feasibility of the new connector concept was demonstrated during seakeeping tests at the Offshore Model Basin located at Escondido, California. The test basin is 295 feet (89.92 m) long, 48 feet (14.63 m) wide and 15 feet (4.57 m) deep. Although the connector concept applies to a generic class of pontoon structure, an emerging pontoon design currently under development by the Navy was used as the test bed. In full scale, this pontoon measures 25 feet (7.62 m) in width, 40 feet (12.19 m) in length, and 8 feet (2.44 m) in depth. Three 1:8 scale models of this pontoon were constructed from plywood and fiberglass for the tests. One pontoon has a perfect shoe-box shape, while the remaining two are seen as blunt at one end and raked 30 degrees at the opposite end (see Figure 8). The connector components were simplified to accentuate functions rather than model strength. Thus spring-loaded pins, alignment pins and receivers were constructed to scale geometrically. The rigging system was modeled in a way to demonstrate the general performance and gross forces on the lines rather representing an exact mockup. An electric winch mounted on one end of a section served the function of equipment that would ordinarily be provided by an attending warping tug. The general layout of the test setup is illustrated in Figure 8**.** Connecting pontoons were placed under a mooring ring truss, near the center of the towing tank, at an initial scale separation of 5 feet (1.52 m). Wire rope played from the electric winch mounted on the leading section (near the wave generator), was attached on deck at the point where the two legs of a marriage bridle came together. Each leg of the bridle, guided by pulley through its respective vacant receiver, was passed over the water and connected to the end of an extended alignment pin on the trailing section. The electric winch was controlled remotely to simulate the action of a winch aboard a positioning tug. A pair of mooring lines from the trailing pontoon was secured to one model barge in order to simulate the coupling between trailing module and its supporting tug. The entire string of pontoons, consisting of leading module, trailing module and "tug," was hooked fore and aft to spring-loaded mooring lines, as shown in Figure 8, in order to model the separation force that would be imposed by sea anchors. The array was pretensioned to 40 pounds (18.16 kg) scale force (i.e., 20,000 pounds [9.08 tons] modeled force) by displacing the 18-foot (5.49-m) springs, which were purposely sized long compared to pontoon surge so that the tension variation in mooring lines would be a minimum. Each pontoon was attached to a Motion Sensing Transducer (MST) that hung from the mooring ring truss. The models were set up initially for tests in head seas. Additional tests conducted at 15 degrees off head seas required that the mooring truss above be rotated and the fore and aft anchor points moved for proper alignment.

Tests were conducted in calm water as well as in regular waves of full-scaled height 4 feet (1.22 m) with periods varying from 4 to 8 seconds, and also in irregular waves representative of sea states 3 and 4. An additional run was conducted in sea state 1 to observe the connection sequence in a condition of minimum wave play. Waves approaching in line and at 15 degrees off the center of the array were used during pontoon module connecting tests.

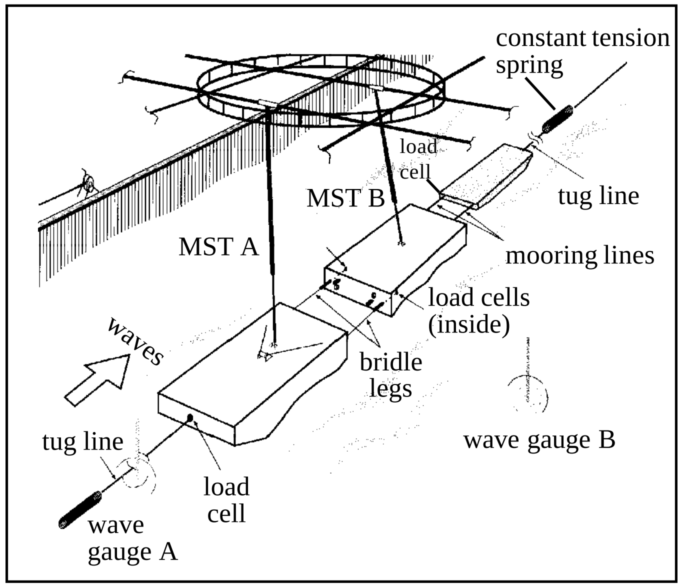

Fig. 8 General test setup.

Model test procedures were designed to resemble an actual operational scenario. Pontoon structures were initially positioned at 5 feet (1.52 m) apart. Tug lines were set to a nominal 40 pounds (18.16 kg) pre-tension required to suppress the wave induced surge motion of the pontoons. The operator remotely controlled the electric winch to reel in the towing lines and gradually brought the pontoons together until all connection pins were properly engaged. This sequence of operations was repeated five times for most of the test runs. Initially, a single pontoon was joined to another single pontoon (1-2 data test), and subsequently a single pontoon was joined to a pontoon couple (1-2+3 test) to model a completed three-module barge.

Data Acquisition

Motions of individual pontoons and couples were measured in six degrees of freedom using a separate MST for each mating structure as illustrated in Figure 8. Tensions in tug lines, mooring lines and bridle legs were measured by load cell. Wave conditions were recorded using two gauges located up stream along the center line of the model assembly, about 16 feet (4.88 m) abeam with the mid-point between two pontoons. A time history of pontoon motion, line tension and incoming wave posture was recorded on a PC-based computer system. The motions measured by the MST were uncoupled according to the CG of each model situation.

Figures 9 to 12 illustrate the data recorded from a typical test run. The particular test was conducted with two individual pontoons connected in sea state 4 with waves coming from 15 degrees off the centerline of pontoon array as in Figure 2. Figure 9 shows the time histories of line tensions in comparison with the separation distance. The pontoons were brought together three times as indicated by the separation reducing to zero. As may be noted, the pretension remains essentially constant over the entire duration, while the tensions on the marriage bridles and mooring lines oscillate more or less in phase with waves, without obvious signs of snap loading. The high tensions in the mooring lines are a result of winch action after pontoons are pressing against each other rather than the occurrence of snapping. Figure 10 illustrates the active motion of pontoons in an elevated sea state. The oblique seas induced substantial lateral motions that must be synchronized by the alignment devices of the connection system. Figures 11 and 12 plot the relative heave displacements and velocities at the adjoining ends as a function of separation distance.

Test Results

The conceptual connection system performed very well in the model basin. Pontoons were connected smoothly in sea states 3 and 4 with little effort from the operator. In over 95 percent of a total 200 trials, alignment pins successfully found the receptacles on the first attempt. In about 3 per cent of the tests, one of the alignment pins jammed at the entrance briefly, but then slipped into the receptacle with the assistance from the following cycle of ambient waves. There were only five instances in which alignment pins did not engage. Each of these events occurred in calm water conditions. The particular problem was that the leading chain-section of an alignment pin had a tendency to slide along the bottom of a receptacle at entry due to its own weight, thereby causing the front end of the thicker trailing elastomeric sleeve to hang at the entrance. A similar problem is unlikely to happen in open water as pontoons continue to welter under wave action. The problem was not witnessed during a test trial in sea state 1 wave conditions. Nevertheless, the deficiency should be correctable by altering the shape of the entrance to the receiver and/or the tips of alignment pins. The test was conducted in waves approaching in line and 15 degrees off the centerline of the pontoon array. The connection operations looked very much the same. The towing lines seemed to be able to overcome the significant lateral motion and align the vessels to engage the connectors.

The recommended method of rigging performed satisfactorily in all seaway conditions tested. The tensioned legs of the marriage bridle directed the alignment pins, which in turn directed the rigid connectors into the proper receptacles as anticipated. The pontoons were brought together in a very smooth manner without obvious collision or sudden snapping of lines. In most cases, a 20-kip (9.08 tons) pretension was sufficient to maintain all lines in tension as evidenced in Figure 9, without obvious slack, excepting a few moments in sea state 4 when large wave groups hit and put the lines on the verge of going slack. This implies that a 20-kip (9.08 tons) pretension may be a minimum requirement to suppress relative surge under this conditions. The pretensioning force is the primary force maintaining pontoons in rough alignment prior to engagement of the alignment pins. A constant tension device introduced as an additional safety measure may be sufficient to prevent snapping of lines and overdrawing by the winch.

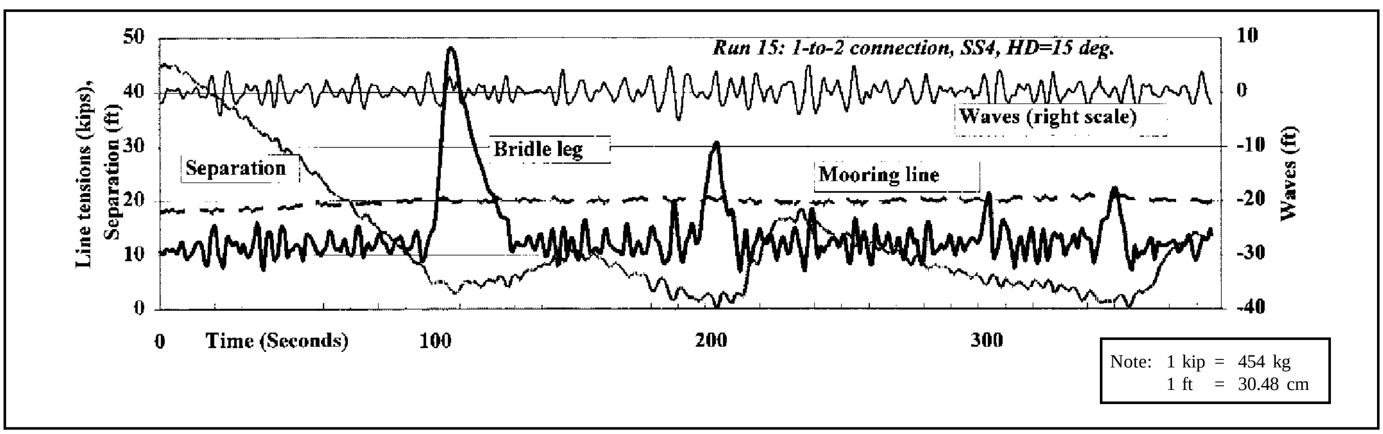

Fig. 9 Time histories of separation distance, line tensions, and ambient waves.

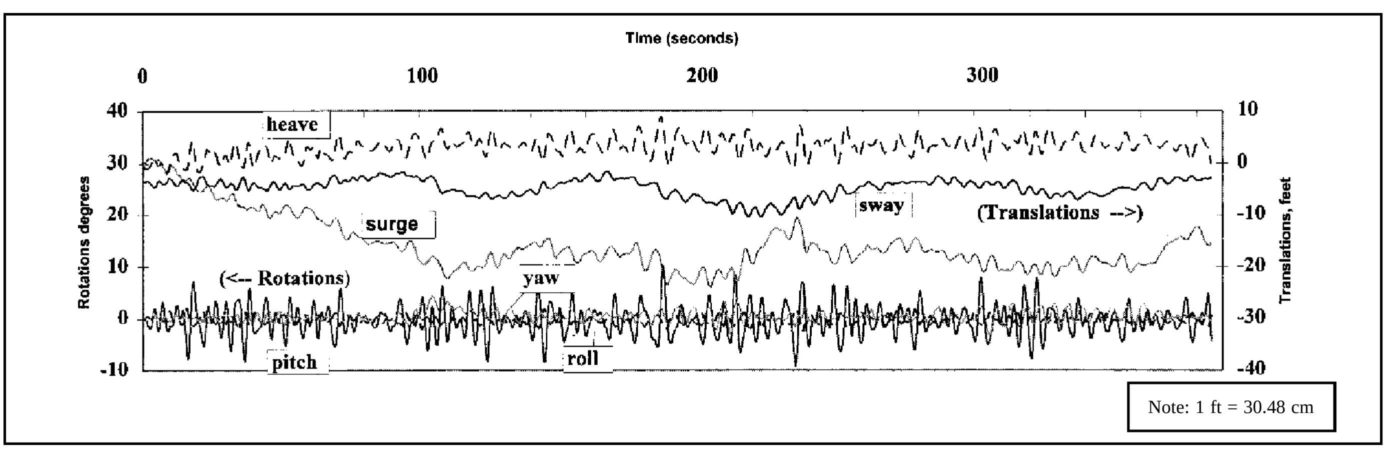

Fig. 10 Time histories of pontoon motions at the center of gravity of the leading Pontoon A.

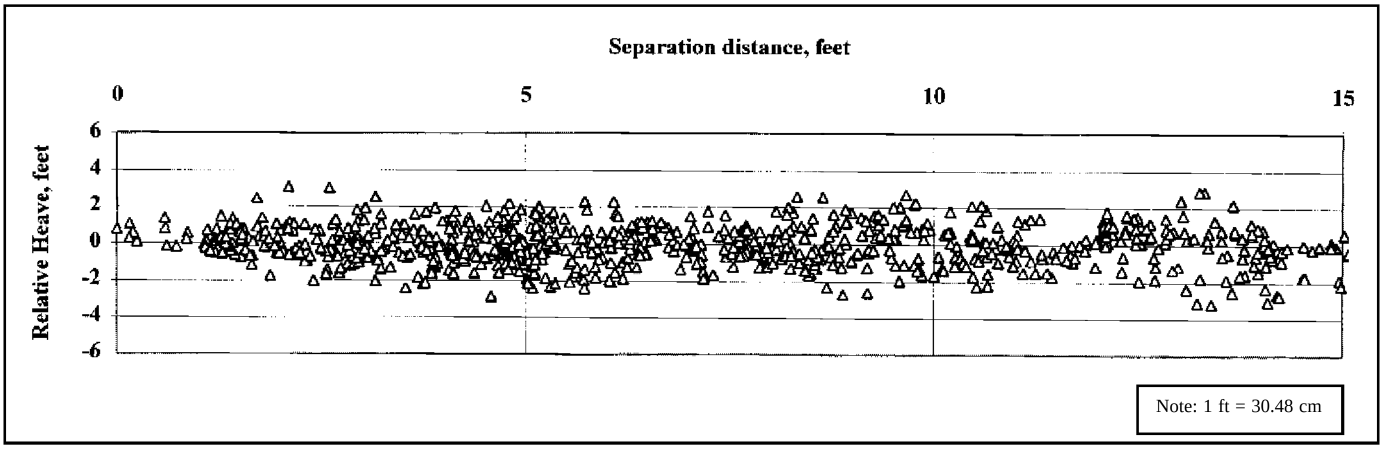

Fig. 11 Relative heave as a function of separation distance.

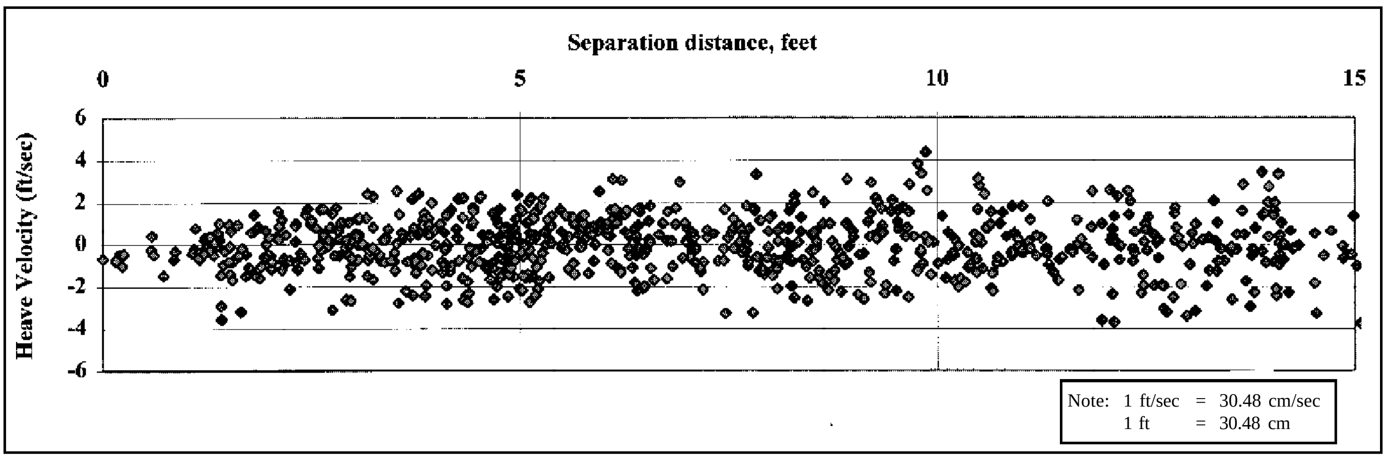

Fig. 12 Relative heave velocity as a function of separation distance.

A primary factor in the success of the proposed concept is attributed to the alignment pins. These members are sufficiently flexible to allow relative rotations and develop sufficient stiffness through bending to synchronize the translational motions of the pontoons. Consequently, these pins are able to align pontoons for rigid connection without experiencing high bending stress. This fact is well illustrated in Figure 11. It may be seen that relative motion between adjoining ends as pontoons are far apart is similar to that predicted theoretically. The maximum elevation difference of two ends at 10-foot (3.05- m) separation is about 5 feet (1.52 m) in sea state 4 (Paulling and Huang, 1995). As modules are brought within 6 feet [1.83 m] (or the length of alignment pins) apart, the sway and heave differentials between the connection ends are restrained to 2 feet (0.61 m). These differentials reduce quickly as the separation distance reduces further to less than 2 feet (0.61 m) (or the length of rigid connectors). At this time, the alignment pins bearing against the receptacles relieve much of the shear and bending which would otherwise appear at the rigid connections. A series of test runs were conducted by intentionally removing the rubber sleeves over the chains to verify this prediction. The appreciably smaller thickness of the chain allows rigid connectors to pitch more extensively and hence heavily loaded the receptacles eventually ripping off one of the receptacles. Figure 12 further confirms the effectiveness of the alignment pins by the fact of significant damping in the heave velocity at the adjoining ends. The effectiveness of the rigging system was further verified in a calm water test of the same system in use for connecting NL causeway sections (Hatch, et al., 1996). While connections with the recommended rigging system took less than 5 minutes to complete, the same operation using a free-stab method without the assistance of the rigging system took an average of 30 minutes. The latter method is essentially impossible in rough seaways.

CONCLUSIONS

The greatest technical challenge to at-sea assembly of floating facilities from modules results from the vigorous random motion between adjoining modules. The connector hardware must be sufficiently flexible to accommodate the random nature of the ambient seaway and, in the meantime, be sufficiently rigid to withstand severe wave forces. Besides, the rapid random motion also prevents direct human action at the adjoining ends and makes maneuvering of heavy equipment extremely difficult. A feasible connection system therefore must not require heavy equipment or precise fits among hardware components.

A conceptual rigid connection offering a high potential of meeting all functional and operational requirements has been conceived. The connection system consists of a unique marriage bridle rigging assembly, a pair of elastomeric molded chains as the alignment device, as well as a versatile rigid connector assembly as the load bearing members and fenders. Seakeeping tests confirmed the concept as highly promising. All critical functions were proven essential and sufficient to the intended mission. The marriage bridle rigging assembly effectively controlled the relative surge behavior of the adjoining modules and enables them to be drawn together without severe collision. The alignment pins were very efficient in restraining relative translations and precisely aligned the modules to allow a smooth engagement of the rigid pins with little effort from the winch operator. The connection was accomplished in a progressive manner that did not require simultaneous engagement of connection hardware. The process required little human interaction other than routine coordination of the tender boats and winch operations. The merits of the system render the proposed concept as highly attractive for application in dangerous open sea operations. The developmental effort now proceeds to the conceptual design stage.

ACKNOWLEDGMENT

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